Debugging an Antenna System

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The antenna is our physical link to the invisible communications medium of radio. Most every design or item we use as an antenna will emit and capture energy. This includes everything from a window screen to a huge, well-designed array. How well the antenna "works" (receiving or transmitting) is termed the "performance envelope."

Every antenna is connected to the transmitter and/or receiver, with the goal of having the best performance possible. Location and installation limitations can restrict the choice of antennas. In these cases, careful planning and antenna selection will produce the system with the greatest performance envelope. In other cases, such as DXpeditions, where people spend substantial resources, consume lots of travel time and even risk life and limb, making sure the performance envelope is at its maximum enables the most QSO's to be made. Isn't that the reason for going??!

An antenna installation always creates excitement, as we venture into the "unknown", not knowing how well it will "work." When first installed, the antenna is checked using some type of device to ensure it is at least close to expectations. Various means are available to test certain aspects of the antenna. The most common test is the VSWR of the antenna. There are many excellent references on this subject, such as Reflections (A.R.R.L.) by Maxwell. The typical antenna installation for amateur use is expected to come close to a VSWR of 1:1 somewhere in the band of use. The highest value in a particular band is often desired to be less than 2:1; however, some shortened antennas will exceed this value and is to be expected. Antennas with high values of VSWR (3-4:1) can be matched using internal or external tuners, often without noticeable performance loss.

The antenna is normally checked on a regular, or continuing basis for not only VSWR, but also for pattern. This is a good practice, as antennas and feedlines can become damaged from a variety of sources. This includes: weather conditions; coax (feedline) contamination; physical damage caused by abrasion leading to loss of jacket integrity; degradation of connections and connectors; rotators that no longer hold the mast; antennas that have slipped on the mast; rodents that have decided to test the flavor of the feedline; indicators that mal-function and other equipment that is no longer accurate; or, new equipment that is inaccurate off the shelf.

The abilities of the amateur station installer or owner vary over a wide range. This can create a difficult scenario for debugging the antenna installation, as there are many variables: antenna type; height; location and proximity to buildings, objects, trees; terrain and station components. The situation is compounded when there is a question during installation and the person being asked is not physically present. This person does not have the opportunity to view the installation, equipment, or environment. The one being asked to find the solution to the installation question(s) is on the other end of the telephone, FAX or e-mail.

The skill of the "remote-analyst" is in their ability to ask the right question of the caller, or otherwise prompt the caller to ask the right question. What provides invaluable assistance is a practical, written overview of antennas and procedure(s) for ensuring the antenna is working properly. If the caller has this available, there is less frustration, more knowledge is gained and the station is on the air quicker.

The following has been prepared after 10 years of sharing time with amateurs from the commercial side and close to 20 years of presentations. This includes speaking with thousands of people at conventions and clubs and hundreds of people designing antenna systems and doing the actual installation.

The information is presented mostly in an outline format. There are occasional explanations included where more description was needed.

It is hoped this effort will improve our enjoyment of amateur radio by increasing our collective knowledge and by increasing the efficiency (expanding the performance envelope) of our antenna system.

73,

OVERVIEW

Basic concept:

The antenna is an electrical device implemented via a mechanical construction; therefore, if it is built properly, it should "work" (especially for production units).

Five, general categories of problem areas:

Test Measurements

Mechanical

Proximity

Feed System

Misunderstandings

Important rule:

Do the simplest and easiest adjustment or correction **first**,and only **ONE (1)** at a time.

Each of the above five (5) categories is looked at in more detail in the following sections.

Category 1:

Test Measurements

A. Test the antenna at a minimum height of 15-20’. This will move the antenna far enough away from the ground (a large capacitor) and enable meaningful measurements. Use saw horses only for construction purposes.

- 15-20’ does not mean 5’ above a 10-15’ high roof;
- Antenna resonant frequency will shift upward as it is raised;
- Feedpoint impedance will change with a change in height (see charts in various books);
- Some antennas are more sensitive to proximity with ground than others.

B. Aiming the antenna upwards, with the reflector on the ground might coincide with some measurements, but there are no guarantees with this method.

C. When dipping using a hand-held meter (i.e. MFJ, AUTEK, AEA), you are looking for the dip in VSWR, not where the impedance or resistance meter indicates 50 ohms. ("Dip" = point of lowest value, or lowest swing on the meter.)

D. Watch for near-by broadcast transmitters.

- The small amount of power used by the hand-held metering devices is no match for several thousand watts.
- The front-ends of the devices are broadband and will receive this out-of-band broadcast energy and "assume" it is reflected energy. This will manifest itself in the meter never showing a low VSWR, sometimes as low as 1.3:1, as high as >5:1; all the while the antenna is actually matched properly.
- The broadcast transmitter will change its power and direction at sunset/sunrise, making daytime and nighttime measurements different.

E. Does the VSWR and frequency of lowest dip change when the coax length is changed? If so, the balun might be faulty.

- With added coax and its associated small (hopefully small) amount of loss:
- the value of VSWR is expected to be lower with the additional coax and,
    - the width of the VSWR curve is expected to be wider with the additional coax, <u>when measured at the transmitter end of the coax</u>.
- the width of the VSWR curve is expected to be wider with the additional coax, <u>when measured at the transmitter end of the coax</u>.

F. Be sure you are watching for the right dip, as some antennas can have a secondary resonance (another "dip").

- It is quite possible to see the reflector frequency, or some other dip caused by adjacent antennas.

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Category 2:

MECHANICAL

A. Are the dimensions correct?

- Production units should match the documentation (within reason)- measure each element after assembly;
- Self-designed units might have a taper error.

B. Making the average taper diameter larger will make the equivalent element physically longer for the same frequency.

C. Making the average taper diameter smaller will make the equivalent element physically shorter for the same frequency.

D. If mono-taper, larger diameter elements will be physically shorter for the same frequency than smaller diameter mono-taper elements.

E. Incorrect mounting / mounting plate allocation.

F. Elements touching the boom in the correct locations?

G. The center of hairpin matching devices can be grounded to the boom.

H. Elements insulated from the boom in the correct locations?

I. The boom is "neutral", but it is still a conductor!

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Category 3:

PROXIMITY

A. What else is near-by (roof, wires, guy lines, gutters). If it can conduct at all, it can couple!

B. Does the VSWR change when it is rotated? If so, this indicates interaction. Note that in some combinations of antennas, there can be destructive interaction even if the VSWR does not change. Computer models can be useful here.

C. What is within 1/4 wavelength of the antenna?

40m = 35' *RADIUS*	think in 3 dimensions
20m = 18' *RADIUS*	like a sphere
15m = 12' *RADIUS*	up and down
10m = 9' *RADIUS*	front and rear

D. Interaction occurs whether or not you are transmitting on the adjacent antennas.

E. Wire antennas under a Yagi can easily affect it. This includes inverted V dipoles for the low bands and multi-band dipoles.

F. Are the higher frequency antennas (Yagis) above the lower frequency ones in the stack?

- Is there adequate distance between the various antennas? Remember, anything within a ¼ wavelength is a potential problem.
- Cross polarization to VHF antennas on mast with HF Yagis is OK.

G. An 80 meter rotatable dipole should be parallel to the boom(s), where it is essentially transparent.

- Other antennas that might interfere *maybe* can be at right angles.

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Category 4:

FEED SYSTEM

The feed system includes the feedline, switching mechanisms, pigtails from the feedpoint on the antenna to the main feedline or switch and all feedlines inside the radio room: the entire connection between the rig and the feedpoint of the antenna.

A. Is the feedline (coax) known to be good?

- If any question, swap it for a known good one.

B. Are the connectors done properly?

- Has a connector been stressed (pulled)?
- Connectors are easy to do, using the right technique.
- Is the rotation loop done properly to not stress the coax?

- Old existing loop, or new one (usually is all right if new)?

C. Is the coax intact, not frayed with the shield coming into contact with anything?

- Can cause sporadic results, as the coax shield touches the tower.
- Is there water in the coax? This can give strange readings, even frequency dependent ones.

D. Is the tuner OFF on the rig?

E. Are there any new devices in the line?

- Might be a good idea to remove everything.

F. Is there a remote antenna switch?

- Swap to another port.

G. Is there a low pass filter in the line?

- The filter can be defective, especially on 10 meters, causing strange VSWR readings.

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Category 5:

MISUNDERSTANDINGS

The antenna can be working properly, but there is a misunderstanding of the anticipated readings vs. the actual readings. There can also be discrepancies between the observed "performance" (i.e. F/B ratio) and the specification(s). Having an open mind here is a great asset and will aid in understanding and resolving the situation.

A. A low VSWR means the antenna has gain.

- No, it only means it is matched to the feedline (remember the dummy load and the light bulb).

B. A high VSWR means the antenna does not have gain.

- No, it only means it is not matched or is fed improperly.

C. A VSWR that does not go to 1:1 is a serious problem.

- No, as long as your rig can tune it, use it.
- Reflected power is not totally lost (see Reflections).

D. My antenna has a great pattern, so it must have a lot of gain.

- No, these two antenna aspects are not necessarily related.

E. Once the antenna is up, it will stay there forever.

- Mechanical devices require periodic maintenance, just like your car.

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Analyzing an Antenna Problem

A specific sequence of steps to take for a systematic resolution of installation questions will make the process easier with less frustration. It will also provide a learning environment and future projects will run smoother and be enjoyable, as the prospect of a higher performance envelope is anticipated!

The following sequence is divided into five (5) parts. Each one addresses a specific aspect of the resolution process. Not all the steps will be used each time a new antenna is installed; however, reading through them will be beneficial.

I hope the length and steps noted do not deter anyone from reading – usually, installation difficulties are simple to resolve.

Typical Debugging Sequence

Part 1

A. The usual reason for debugging is that the VSWR is not as expected. This is the only measurement that can be reliably made by the majority of people.

- If the VSWR is showing high values (4:1 or higher), do not attempt any adjustment of the antenna before first certifying the feed system is correct.
- High values like this are so far away from the expected values that they essentially eliminate the antenna from being the current problem.

B. Remove all devices in the feed system to eliminate possible components with problems, such as low pass filters (especially if 10 meter VSWR readings are not as expected); therefore, we want to work as directly as possible with the antenna in a good location.

C. Isolate the feed system as the first step.

- Place a 50 ohm dummy load at the antenna end of the coax feedline;
- Measure the VSWR of the coax feedline at the transmitter end (dummy load at the other);
- If anything other than a low VSWR (1.2:1 or less), the coax should be changed; and/or,
- If you see a significant drop in power through the coax (need to use a watt meter here), the coax should be replaced.
- If the coax is good, proceed to the next steps.

D. Is the antenna at a reasonable height above ground?

- 15-20’ above ground and roof;
- If not, have as high as possible and watch for proximity effects.

E. Does the VSWR change as it is rotated?

- What else is on the mast?
- Any wire antennas nearby?
- What it is rotating over/under to cause a change in measurement?

F. Are the element lengths correct?

G. Are the elements in the proper location?

H. If a hand-held test unit is used, is there a broadcast transmitter within several miles?

- Very important on 160, 80/75, 40 meter antennas.

Part 2

A. Stay calm.

B. Do the easiest thing(s) first.

C. If a simple change was made (i.e. moving one element a few inches), the problem is most often in the feed system.

D. Swap the coax even if it takes some effort.

E. Try to remove the parts of the antenna feed system one at a time to isolate the culprit.

F. Be sure to track the correct dip in VSWR readings.

G. On production antennas, >99.9% are fixed through:

- Element length / tuning verification (and location, but extremely rare).
- Local broadcast transmitter affecting readings - use your transmitters VSWR meter.
- Antenna mounted properly; clear of proximity issues, including conductive guy wires.
- Correct feedline and matching system adjusted properly.
- (The >99.9% figure is from Force 12 product records; 7 antennas required something else. Have no tracking of other manufacturer’s data.)

Part 3

A. If you decide to make a change, do only 1 item at a time.

- If you change more than one item, you will not know what caused the observed change.
- If nothing appeared to change and more than one item was changed, it is possible (more than likely) the several items that were changed countered the effect(s) of each other.
- Changing more than one item makes it IMPOSSIBLE to track.

B. Write on your note pad the initial observation(s) and the conditions, such as height and proximity.

- This will increase your awareness of the situation; and,
- It will provide a documented starting point.

C. Keep notes of each step taken.

- A yellow pad is excellent - number the steps and each page.
- Write what was done and then write the observed result.
- Underline the amount of a change and use +/- sign, or say "longer" or "shorter."

Part 4

A. For non-production, or "one-off" antennas:

- First, follow same procedures as for production antennas.
- Element tapering needs to be verified.
- Element mountings are not properly accounted for (i.e. insulating boots when using old Hy-Gain mounts for a new design)
- Matching techniques might not be as expected.
- Check the feedpoint without the matching device in place.
  - A hairpin will step up the impedance and might just move it to the high side of 50 ohms, making adjustment (down) to 50 ohms impossible.
  - If the design is a "forward stagger" type, the forward Yagi needs to be shorted across the feedpoint (i.e. hairpin); otherwise, the driver will have an open or shorted coaxial stub (the pigtail feeding it) attached across it.

B. Keep a design notebook, with as much detail as possible.

- Same notes-taking procedure as described earlier is invaluable.

Part 5

ON AIR Observations

A. F/B less than expected.

- Antenna height affects F/B, so does the angle being used. Refer to typical plots to acquaint yourself

with these issues.
- F/B specification might be too ambitious. Some specifications are given as peak values, available only across a narrow frequency range (if not tuned properly, might be out of band).efer to typical plots to acquaint yourself with these issues.
- How much to expect?
    - A 2 element full size parasitic Yagi will be around 12-16dB and A 2 element shortened, loaded Yagi can be >20dB if tuned properly.
    - A 3 element full size Yagi "naturally" wants to be around 20dB.
    - Stacked Yagis on one mast (i.e. 20-15-10) can greatly affect the F/B.
- Rotator clamps not secure, mast slipping.
- Antenna attachment not secure, antenna slipping (typical with hard steel masts).

B. How much gain (redistribution of energy) to expect?

Here are real-life, reasonable, verifiable figures for full size 20 meter Yagi antennas, compared to a full size dipole reference (the dipole is in the exact same location as the Yagi, such as over ground):

0 dBd	Dipole Reference	Compared to Isotropic Source (dBi)	@ 74' above real ground,compared to Isotropic Source (added 5.8dB for ground reflection gain)
4.5 dBd	2 ele, 10' boom for 20 meters	6.64 dBi (added 2.14 dB for Isotropic Source)	12.44 dBi (added 5.8dB for reflection gain)
5.5 dBd	3 ele, 20' boom	7.64 dBi	13.44 dBi
6.5 dBd	4 ele, 30' boom	8.64 dBi	14.44 dBi
7.5 dBd	5/6 ele, 42' boom	9.64 dBi	15.44 dBi
8.5 dBd	7 ele, 60' boom	10.64 dBi	16.44 dBi
9.5 dBd	8 ele, 80' boom	11.64 dBi	17.44 dBi
10.5dBd	9 ele, 105' boom	12.64 dBi	18.44 dBi
12.5dBd	12 ele, 175' boom	14.64 dBi	20.44 dBi
14.5dBd	20 ele, 330' boom	16.64 dBi	22.44 dBi

These examples show how gain figures can be increased. The gain compared to the reference dipole is increased by 2.14dB when comparing to the isotropic source (i.e. 4.5dB + 2.14 = 6.64dBi); and if ground reflection gain is also included (i.e. at 1 wavelength above ground), add another 5.8dB. Using both of these, the 5.5dB figure for a 3 ele Yagi becomes 13.44dBi. Whichever the case, the reference must be specified; otherwise, you know nothing about the antenna. See Force 12 Antenna Specifications and the book Array of Light for more information.

NOTE: if you are reading gain figures that are higher than the above numbers for the same boom length on a Yagi antenna, ask for specific verification. This is especially prudent when the antenna contains components that can cause loss, such as traps, phasing systems, coils and the like. There is "no free lunch" here andthere are no "magic" designs."

C. Does not seem to be competitive, or crack pile-ups.

- Not aimed in the right direction (being off 30 degrees can be a lot).
- Gain specification in error, or loss in the antenna system.
- Coax, switches, antenna tuning, antenna components, radial system.

- Operating techniques need improvement!
- **Join a local contest club!!**

I hope this write-up provides a basis for understanding antennas and installations. There is certainly more that can be covered; however, this should provide a working platform for typical installations.

CU on the air!

N6BT

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